



“The Development of a Methodology for Automated Sorting In the Minerals Industry”

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*I certify that all material in this thesis which is not my own work has been
identified and that no material is included for which a degree has previously
been conferred upon me.*

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Abstract

The objective of this research project was to develop a methodology to establish the potential of automated sorting for a minerals application. Such methodologies, have been developed for testwork in many established mineral processing disciplines. These techniques ensure that data is reproducible and that testing can be undertaken in a quick and efficient manner. Due to the relatively recent development of automated sorters as a mineral processing technique, such guidelines have yet to be established.

The methodology developed was applied to two practical applications including the separation of a Ni/Cu sulphide ore. This experimentation also highlighted the advantages of multi-sensor sorting and illustrated a means by which sorters can be used as multi-output machines; generating a number of tailored concentrates for down-stream processing. This is in contrast to the traditional view of sorters as a simple binary, concentrate/waste pre-concentration technique.

A further key result of the research was the emulation of expert-based training using unsupervised clustering techniques and neural networks for colour quantisation. These techniques add flexibility and value to sorters in the minerals industry as they do not require a trained expert and so allow machines to be optimised by mine operators as conditions vary. The techniques also have an advantage as they complete the task of colour quantisation in a fraction of the time taken for an expert and so lend themselves well to the quick and efficient determination of automated sorting for a minerals application.

Future research should focus on the advancement and application of neural networks to colour quantisation in conjunction with traditional training methods. Further to this research should concentrate on practical applications utilising a multi-sensor, multi-output approach to automated sorting.

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List of Abbreviations and Acronyms

ASCII	American Standard Code for Information Interchange
AHC	Agglomerative Hierarchical Clustering
AST	Applied Sorting Technology pty ltd
BMP	BitMaP
CCD	Charged Couple Device
CEN	Comité Européen de Normalisation (European Community for Standardisation)
CL	Competitive Learning
CLINK	Complete LINKage clustering
COG	Centre Of Gravity
COLEL	COLOUR ELement
DEXRT	Dual Energy X-Ray Tomography
DIP	Digital Image Processing
ECS	Eddy Current Separator
EDX	Energy Dispersive X-ray analyser
EM	ElectroMagnetic radiation/spectrum
EMS	ElectromMagnetic Separator
ESM	Electronic Sorting Machine company
FIR	Far-InfraRed radiation
GCME	Genetic C-Means Algorithm
GmbH	Gesellschaft mit beschränkter Haftung (a limited company)
HCL	Hybrid Competitive Learning
HDPE	High Density PolyEthylene
ICT	Intervalence Charge Transfers
INCO	International Nickel Company
IR	InfraRed radiation

KSOM	Kohonen Self Organising Map
LIBS	Laser Induced Breakdown Spectroscopy
LIF	Laser Induced Fluorescence
LOI	Loss On Ignition
MIR	Mid-InfraRed radiation
MLA	Mineral Liberation Analyser
MP	Microprobe
MRF	Metal Recovery Facility
MSS	Magnetic Separation Systems
NIR	Near-InfraRed radiation
NMR	Nuclear Magnetic Resonance
OM	Optical Microscope
PET	PolyEthylene Terephthalate
PGE	Platinum Group Element
PMCC	Product Moment Correlation Coefficient
PMMA	PolyMethyl MethaCrylate
PPM	Portable Pixel Map
PTFE	PolyTetraFluroEthylene
PVC	PolyVinyl Chloride
QEM*SEM	Quantitative Evaluation of Minerals by Scanning Electron Microscope
RPCL	Rival Penalised Competitive Learning
SEM	Scanning Electron Microscope
SL#	Supervision Level #
SLINK	Single LINKage clustering
Tph	Tonnes per hour
UDNN	User Defined Nearest Neighbour approach
UK	United Kingdom

UPGMA	Un-weighted Pair Group using arithmetic Averages
UV	UltraViolet radiation
VBA	Visual Basic for Applications
VP-SEM	Variable Pressure – Scanning Electron Microscope
WTA	Winner Takes All
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

List of Symbols

A	atomic number
a	length of longest axis
B	constant over range between absorption edges
b	length of shortest axis (pixels)
C	constant for converting breadths to equivalent square sieve sizes
c	velocity of light in a vacuum (ms^{-1})
E	radiant Energy (J)
e_{ij}	Euclidean distance
eV	electron Volt
h	Planck's constant
H_0	null hypothesis
H_1	alternative hypothesis
$h_{c(x_j),i}$	Neighbourhood function
l	length
m_i	model vectors or cluster centres
m_c	best matching model vector or cluster centre
n	total number of particles in sample
n_{S_j}	number of input vectors within tessellation
N_A	Avogadro's Number
P	radiant power (W)
r	number of particles retained on asieve
r_i	position of model vector in the output layer of KSOM
S_j	tessellation of model vector j

SA	Surface Area (pixels ² or m ²)
SF	Shape Factor
t	iterative step
W	weight fraction within sample (kg)
w	width
w_m	width of a cluster
x_j	input vector
“	Inch
$\alpha(t)$	Learning rate at iterative step t
γ_i	Conscience factor for RPCL algorithm
ε	constant for converting breadth to mean thickness
θ	angle of measurement
λ	wavelength of radiation (nm) or maximum boundary of material in PACT
μ	linear absorption co-efficient
μ_m	mass absorption co-efficient
ν	frequency of radiation (Hz)
ρ	density (kgm ⁻³) or objective error function
$\rho(s_z)$	pruning function for RPCL algorithm
$\sigma(t)$	width of neighbourhood at iterative step t
τ	minimum distance between clusters before pruning in RPCL algorithm
χ	principle axis of particle in PACT
ϕ	minimum boundary of material in PACT